MPAGS Astrophysical Techniques
Lecture 2 - CCDs, Photometry and Spectroscopy

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Please email Daniel (d.bayliss@warwick.ac.uk) or Matteo (m.brogi@warwick.ac.uk) your answers (can be scans of hand-written answers). There is no mark associated with the assignment, as the aim is that you engage with the topic. We will just keep note of whether you tried these questions. All the fits files and scripts required for this worksheet, along with the slides from the lecture, are located here:
`https://drive.google.com/open?id=17r42LOOVS2jVvyrJcAaRjVL5kInvqb8f`

CCD Images

1. We are going to examine FITS images taken with Las Cumbres Observatory 0.4 m telescope situated at Haleakala in Hawaii. Such images can be found at https://archive.lco.global, however we make them available for you in the zipped directory.

   Take a look at the following FITS frames in the directory:

   - `ogg0m404-kb82-20180501-0017-b00.fits` (a bias)
   - `ogg0m406-kb27-20180501-0022-d00.fits` (a dark)
   - `ogg0m406-kb27-20180430-0078-f00.fits` (a sky flat)
   - `ogg0m406-kb27-20171108-0098-e91.fits` (a reduced science frame)

   Why is the reduced frame 8MB while the other frames are only 3MB?

2. Using `DS9` (latest version is 8.0) open the bias frame. I sugggest you change scale to ”zscale” to better see the image. Remember this is a 0 second exposure taken without opening the shutter. What is the approximate bias level for this camera?

3. Using `DS9` open the dark frame. Remember the dark frame is an exposure of a set time that is taken without opening the shutter. Using the menu ”File”, ”Display Fits Header” check the exposure time for this dark frame. What is the exposure time? What are visual differences between this dark frame and the fits frame? How does the mean count vary between the dark frame and the bias frame, and what is the cause of this difference?

4. Using `DS9` open the flat frame. Remember the flat frame is an exposure of a set time that is taken by imaging a uniform light source such as a screen or the twilight sky. What are visual differences between this flat frame and the dark frame?

Photometry

1. We are going to measure the brightness of the stars in the reduced science frame. Normally this would be done with software such as Source Extractor. However we are going to use `DS9` for this task. To begin with open the file: ogg0m406-kb27-20171108-0098-e91.fits. Change scale to zscale, and zoom into the central region and identify the star at pixel location (X=768,Y=500). What is the RA and Dec. of this star, and can you look up its name/identifier?

2. From the "Edit" menu chose "Region", and from the "Region" menu select "Circle". You can now draw a circular aperture around the star. Click on the aperture and you can edit the center and radius of the aperture. Change units to "physical" to work in pixel units. What do you think would be the radius of the correct photometric aperture for this star?

3. Double click on the circular aperture and you will get a window with information on the region. Now in the menu bar you can select "Analysis", and then "Statistics". What is the total ADU count in your aperture?

4. Now drag your aperture region to a nearby patch of sky without any visible stars. You can repeat the analysis to get the total sky counts in the same sized aperture. What is the ADU count for the sky in your aperture? Hence what do you estimate the ADU count is for just the target star (sky subtracted)?

5. Now you need to find reference stars. Good reference stars will be isolated and a similar brightness to the target. Pick 5 reference stars and write down their X,Y pixel locations and the total ADU for each star. Do you think each star should have the same sized aperture? Explain your reasoning. Is the sky background different for each star?

6. Divide the target ADU count by the sum of the 5 reference stars and note the number. This is the relative photometry for the target star. Applying this to a series of images allows one to monitor any variations of brightness in the target star due to events such as flares, transiting planets, eclipsing stars, micro-lensing, etc. That is it! You have performed relative photometry on the target star for a single frame.

Spectroscopy

1. Open the spectroscopic flat `flat.fits` with `DS9`. What is the main difference with an imaging flat field image? What extra step is required to make this flat usable to correct science images?

2. Open the master flat field `mflat.fits`, obtained by co-adding a sequence of processed flat fields, with `DS9`. Can you spot regions where the correction of science frames might still not work appropriately?

3. Open the science spectrum `science_spec.fits` with `DS9`. How many sources do you see in the image? What are the spectral and the spatial directions? How was the slit oriented with respect to the image coordinates?

4. We will now use `DS9` to drag lines tracing the position of the spectral trails. These will be subsequently used to extract the 1-D spectrum. Make sure `Edit` → `Region` is selected from the scroll-down menu at the top, and adjust the zoom and color scaling parameters. Select `Region` → `Shape` → `Line` and draw a line on top of each spectral trace. Lines can be selected and moved / resized with one click. Double-clicking allows you to manually specify start and end points. When you are happy with the result, save the region file with `Region` → `Save Regions`. In the pop-up window make sure to select your current folder, and use `trails.reg` as file name. In the last pop-up window, select `'DS9'` as `'Format'` and `'Physical'` as `'Coordinate System'`.

5. Run the Python script `extract_spectra.py`. It will use the regions you identified and saved, compute and remove the sky around each of the spectral trails, and extract the 1-D spectra by co-adding the trails along the spatial direction. The code will save two Python Numpy arrays (`spec1.npy` and `spec2.npy`) containing the two extracted spectra. It will also save the spectrum of the sky as `sky.npy`.

6. Use Python's `matplotlib` library to plot the spectrum of the sky. This entails loading in the previously saved numpy array. Plotting is a key skill in research, so feel free to experiment with options. Once you are happy with the result, inspect the spectrum. Contrarily to what we discussed in class, sky emission lines are not clearly visible. Conversely the spectrum is smooth and appears low-resolution. What does it reveal about the entrance slit?

7. Use Python's `matplotlib` library to plot the spectrum of the two sources. Even if the data has not been calibrated in flux, could you tell which one of the two stars is hotter? Why?

8. The web page `https://www.cfa.harvard.edu/~pberlind/atlas/atframes.html` contains spectra of stars as function of spectral type. Try to classify the spectra of the two sources. If you are in trouble, focus on the main spectral classes (A, F, G, K, M, etc.) and neglect the sub-class (0-9) or evolutionary stage (III-IV-V). (*Hint: since our spectra have not been calibrated in flux, the shape of their envelopes will differ from that of the atlas. Your comparison should therefore rely on spectral lines / bands*).

9. Among the methods discussed for wavelength calibration, which one(s) would be applicable to these data?